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REVEGETATION AND CHEMICAL COMPOSITION OF MINE AND MILL TAILINGS - ASARCO, BUCHANS, NEWFOUNDLAND

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ABSTRACT

This report presents information on various aspects of a program of revegetation of mine and mill tailings at ASARCO Mines, Buchans, Newfoundland. The information deals with the success of seeded species, colonization by native species following seeding, chemical compositions of tailings and vegetation and suitability of the revegetated area as pasture.

In seeding trials over a period of three years (1975-77) the tailings rich in heavy metals were successfully revegetated using a mixture of annual rye, birdsfoot trefoil and creeping red fescue. The seeded areas needed preseeding ground preparation, and pre- and post-seeding fertilizer applications.

The levels of macro- and trace-elements in foliage were within the reported limits in vegetation growing on normal soils. Field tests on farm animals are recommended to evaluate the use of revegetated areas as pastures.

RESUME

Cet exposé contient de l'information sur divers aspects d'un programme de revégétation de déchets miniers aux Mines ASARCO. Le rapport traite aussi du succès obtenu par ensemencement, de l'implantation d'espèces indigènes suite à l'ensemencement, de la composition chimique des résidus miniers et des plantes ainsi que des possibilités d'utilisation des surfaces revégétées comme terrains de paturâge.

Des essais d'application pendant une période de trois ans (1975-77) ont aboutit en un programme de revégétation utilisant un mélange de seigle, de trèfle et de fétuque. Les terrains ensemencés doivent être préparés convenablement au préalable et des engrais doivent être appliqués avant et après la semence.

Les concentrations des éléments majeurs et des éléments en quantités de traces dans les feuillages correspondaient aux résultats connus pour des plantes provenant de sols normaux. Des essais pratiques sur des animaux de ferme sont recommendés afin d'évaluer le potentiel d'utilisation de ces terrains comme paturâges.

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by

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1. BACKGROUND

The operations of ASARCO (American Smelting and Refining Company) at Buchans, Newfoundland involve mining and concentrating of copper, zinc and lead with ancillary extraction of gold and silver. During the concentrating process huge quantities of finely ground rock and some untrapped minerals designated as 'mill tailings', are discharged in the form of a slurry into settling ponds. Also during the mining operations after the ore is mined, sand is used to backfill the void. However, before the sand is pumped underground, fine portions are removed from the sand using cyclones. This fine portion separated from sand is designated as 'sand slimes' and is also pumped into settling ponds covering extensive areas. After the 'mill tailings' and 'sand slimes' in settling ponds drain and dry, they present serious dust problems over an extensive area, including the town of Buchans (see cover photo).

To alleviate this dust problem, a revegetation program was initiated by ASARCO in cooperation with the Water Pollution Control Directorate, Environmental Protection Services (DOE), and EROCON Ltd., Don Mills, Ontario. Additional help and advice were provided by personnel

of Agriculture Canada and the Newfoundland Department of Agriculture. The Canadian Forestry Service was requested by the EPS and ASARCO to evaluate a preliminary revegetation trial and to determine chemical composition of seeded and natural vegetation. This report presents information on i) field operations carried out by ASARCO, ii) success of seeded species and invasion of the seeded areas by native species, and iii) chemical composition of soil (mill tailings and sand slimes) and vegetation.

2. METHODS

Field methods involved site preparation, seeding, fertilizer application, sampling of soil and vegetation for chemical analysis and ground surveys for vegetation and species composition.

2.1 Site Preparation

Three areas were seeded from 1975 to 1977 following the same methods of site preparation every year (Fig. 1). The mill tailings and sand slimes which underwent the various field treatments will be simply termed 'soil' in the text of this report.

The upper 10 - 15 cm of soil were turned over by a disc harrow attached to a farm tractor (Fig. 2). The lime and fertilizer were applied by a cyclone seed spreader followed by breaking of the lumps and levelling of soil by a chain rake (Figs. 3 and 4). Seeding was done using a cyclone seeder mounted at the back of a farm tractor. After seeding the soil was rolled with a one ton drum roller towed by a tractor (Fig. 5).

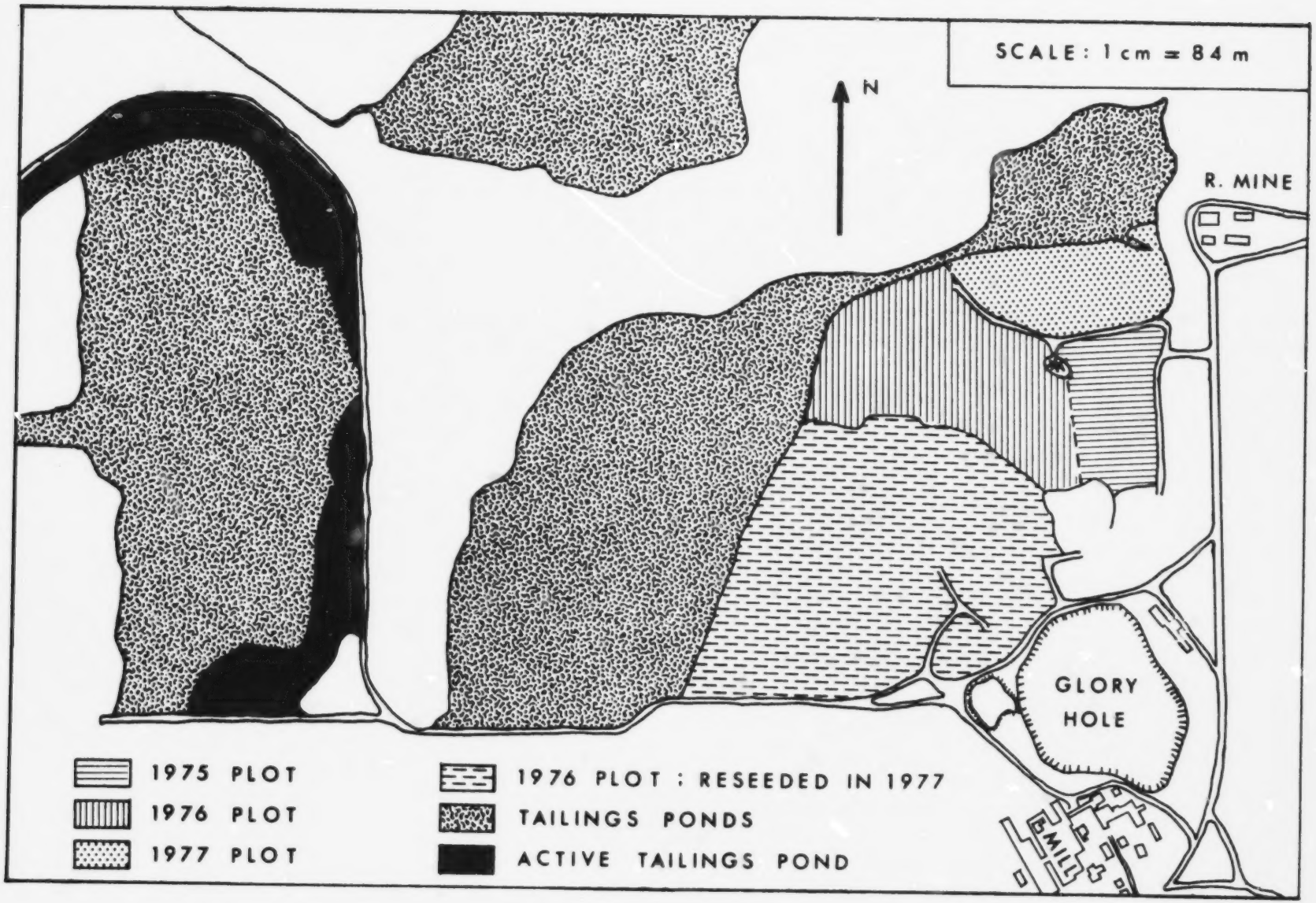
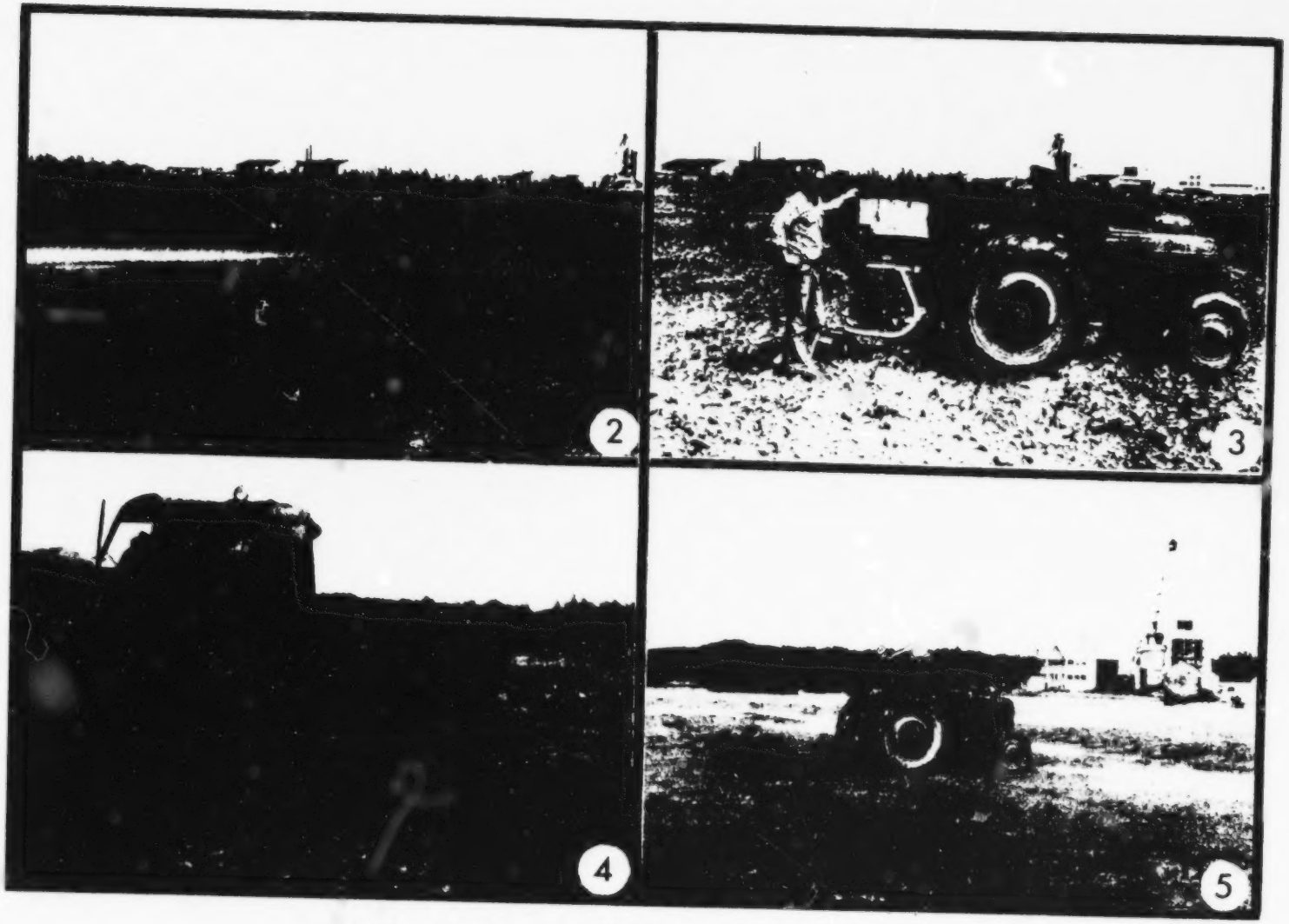


FIGURE 1. AREAS OF 1975 TO 1977 SEEDINGS.



(For explanation to Figs. 2-5, see page 27)

2.2 Preliminary Revegetation Trial

A preliminary seeding experiment was established between June 25-29, 1974 under contract with EROCON Ltd. Details on species, rates of fertilization and liming and on companion crops are as follows:

I. Species seeded:

a) Lotus corniculatus cv Empire (birdsfoot trefoil)

b) Poa pratensis cv Meirion (Kentucky blue)

c) Festuca rubra (creeping red fescue)

d) Phalaris arundinacea cv Frontier (reed canary)

II. Rate of fertilizer:

a) Nil

b) 336 kg/ha of 10-20-20

c) 672 kg/ha of 10-20-20

d) 1 008 kg/ha of 10-20-20

III. Rate of liming:

a) Nil

b) 2 240 kg CaO/ha

IV. Companion crop:

a) Nil

b) 56 kg/ha of annual rye

The experimental design was such that there was one plot (1.52 m x 3.05 m) for each of the combination treatment of species x fertilizer rate x lime rate x absence or presence of the companion crop. There was no replication of any treatment.

The results of the preliminary seeding trial indicated that trefoil, annual rye and red fescue were the promising species at a fertilizer rate of 1 008 kg/ha. The initial establishment of these species in the experimental plots was patchy, possibly due to the deposit of wind blown soil on the small experimental plots. No differences were observed by EROCON between limed and unlimed plots.

2.3 Large Scale Seedings

Large scale seedings were undertaken from 1975 to 1977. The 1975 plot (4.5 ha) was seeded on May 28 using the following species-mixture and fertilizer rate:

Birdsfoot trefoil	- 22.4 kg/ha
Red fescue	- 30.6 kg/ha
Annual rye grass	- 56 kg/ha
12-24-24 fertilizer	- 1 120 kg/ha

The rye-grass cover from the above seeded rates was too dense and as a result seeding mixture for 1976 and 1977 seedings was modified and lime was added at the recommendations of Canada Agriculture:

Birdsfoot trefoil	- 22.4 kg/ha
Red fescue	- 44.8 kg/ha
Annual rye grass	- 16.8 kg/ha
12-24-24 fertilizer	- 1 120 kg/ha
Lime (CaO)	- 1 120 kg/ha

The 1976 (26.3 ha) and 1977 (4.8 ha) plots were seeded on June 5 and 6 respectively.

2.4 Chemical Analysis of Sand Slimes and Tailings

Two bulk soil samples of each of the sand slimes and tailings were collected at 0 - 15 cm and 15.1 - 25 cm depths from a 4.5 ha plot prior to site preparation and seeding in spring of 1975. The soil samples were analysed for texture; pH; percent organic matter (O.M.); total and available phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), manganese (Mn), cobalt (Co), copper (Cu), zinc (Zn), lead (Pb), iron (Fe), cromium (Cr), nickel (Ni) and aluminum (Al). The methods used were standard methods of analysis summarized by Dawe (1972)*.

2.5 Analysis of Plant Samples

Plant sampling involved the collection of foliage samples from seeded and native species growing on mine tailings, on the edge of a pond receiving slime discharge and in the natural forest 100 m from the slime-receiving pond (Table 2). The foliage samples were dried at 70°C and ground to pass through 70-mesh size (212 µm sieve opening) in preparation for chemical analysis. The ground foliage samples were analysed for nitrogen, phosphorus, potassium, calcium, magnesium, manganese, sodium, iron, copper, cobalt, nickel, aluminum, boron, lead, zinc and cromium by standard methods (Dawe 1972)*.

2.6 Ground Survey for Vegetation Cover and Species Composition

Each revegetated area was surveyed for species cover and presence by placing thirty 50 cm x 50 cm quadrats at regular intervals within the boundaries of the area. Each quadrat was subdivided into

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*Dawe, E.R. 1972. The Soils Laboratory and its operation - Newfoundland Forest Research Centre, St. John's, Newfoundland. Int. Rep. N-52, 33 pp.

twenty-five 10 cm x 10 cm quadrats. Within each subquadrat, visual estimates of ground covered by each species present were recorded. Average of 30 quadrats for each species are presented in Table 1.

3. RESULTS AND DISCUSSION

3.1 Success of Large Scale Seedings

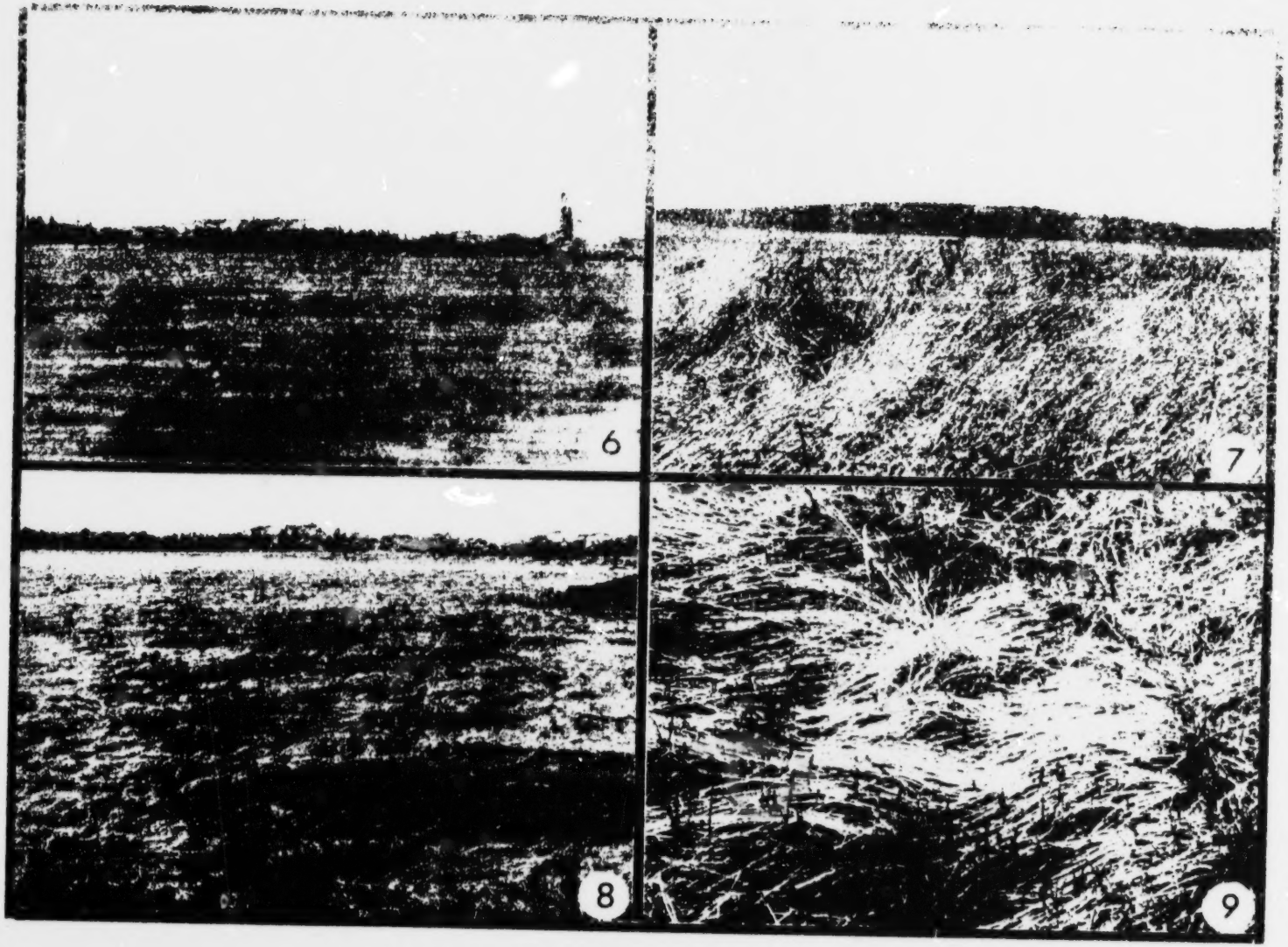
1975 Seeding: The 1975 seeding trial resulted in an excellent grass cover over an area of 4.5 ha (Figs. 6-10). During the summer and fall of the same year the grass cover comprised 75% annual rye, 20% red fescue and 5% trefoil in combination with native plant species such as horsetails, mosses and liverworts. The rye-grass was too dense and could have suppressed the growth of other species. Surveys of the plots in spring and fall of 1978 showed that 75-80% of the ground was covered with living or dead vegetation (Table 1). The legume, birdsfoot trefoil, covered an average of 21 - 25% of the ground. During the 1978 survey numerous current year seedlings of this species were observed in some parts of the 1975 plot. Probably these originated from the self-seeding habit of the legume.

1976 Seeding: Because of the dense cover of rye grass resulting from 1975 seeding, its seeding rate was reduced from 56 to 16.8 kg/ha. Approximately 26.3 ha were seeded in June 1976. The grass cover established successfully in the beginning, however, at the end of July it suffered a serious damage by black cutworm (Agrotis ipsilon Hufnagel) which destroyed the grass cover completely over an area of 35 acres.

Table 1. Percent ground covered by seeded and native species in 1975-77 plots, cover measured in May and September 1978.

Species present	1975 seeding		1976 seeding		1977 seeding	
	May '78	Sept. '78	May '78	Sept. '78	May '78	Sept. '78
1) Alder (Alnus rugosa (Du Roi) Spreng.)	✓	✓	✓	✓	✓	✓
2) Annual rye (Lodium multiflorum Lam.)	✓	✓	✓	✓	18.5	✓
3) Birdsfoot - Trefoil (Lotus corniculatum L.)	25.0	21.0	✓	10.0	✓	23.5
4) Bullrush (Scirpus atrocinctus Fern.)	✓	✓	✓	✓	✓	✓
5) Clover (Trifolium repens L. and T. pratense L.)	✓	✓	✓	✓	✓	1.0
6) Creeping red fescue (Festuca rubra L.)	11.5	35.0	10.0	25.5	15.5	28.0
7) Dry grass-cover (mostly annual rye and red fescue)	34.0	14.5	72.0	8.5	46.0	25.0
8) Fireweed (Epilobium angustifolium L.)	-	✓	-	1.5	-	✓
9) Horsetail (Equisetum arvense L.)	✓	✓	✓	✓	✓	✓
10) Liverworts	-	-	-	0.5	-	-
11) Mosses	4.0	10.0	1.0	30.0	✓	✓
12) Pearly everlasting (Anaphalis margaritacea var. subalpina Gray)	-	✓	-	✓	-	✓
13) Red top (Agrostis scabra Willd.)	-	✓	-	4.0	-	-
14) Willow (Salix discolor Muhl.)	✓	✓	-	-	-	-
15) Bare ground	25.5	19.0	17.0	20.0	20.0	22.5

Note: * = Av. of thirty 50 cm x 50 cm quadrats.
✓ = Species present with < 0.5% cover.
- = Species not present.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The whole 1976 plot was reseeded in August 1977. The cutworm was controlled by an application of Phosdel (2.1 kg/ha) on approximately half of the infested area and chlordane (2.8 kg/ha) on the remainder. A survey of the area in 1978 revealed that 80% of the ground was covered by vegetation. Moss cover in the 1976 plot was exceptionally high (30%), and was restricted to wet areas. Among the grasses, creeping red fescue was the most common followed by annual rye and red top. The legume, birdsfoot trefoil, covered 10% of the ground. Other less frequent species are listed in Table 1.

1977 Seeding: An approximate 4.8 ha were seeded on 6 June 1977 using the 1976 seeding mixture and fertilizer rates. The surveys of the area in May and September 1978, revealed a good establishment of grass cover (Fig. 11). Up to 80% of the ground was covered and the relative cover of various seeded and native species present is given in Table 1. Common grasses included red fescue and annual rye. Legumes, birdsfoot trefoil and clover, covered 24% of the ground area.

The results of 1975-77 seeding trials showed that mill and mine tailings rich in heavy metals were successfully revegetated using a mixture of annual rye, birdsfoot trefoil and creeping red fescue. Preseeding site preparation liming, and pre-seeding fertilizer applications are recommended for successful revegetation of the tailings. The use of revegetated areas for pasturing is not recommended before animal feeding trials to determine the effect of heavy metal dust in their diet are undertaken. Frischknecht (1978) commented that revegetation is not the end of stabilization process on mined lands. He concluded from his work in the U.S.A. that it would take a) 5 years for

Figures 2-11. Fig. 2. Disc-harrowing of 1975 plot, 20 May 1975. Fig. 3. Cyclone seed spreader used for lime and fertilizer applications and seeding. Fig. 4. Chain-rake employed for lump-breaking and levelling of soil. Fig. 5. One-ton rolling drum used after seeding. Fig. 6. 1975 plot photographed on 18 June 1975 showing the early stages of the establishment of vegetation cover. Fig. 7. 1975 plot showing the complete establishment of vegetation cover by 26 August 1975. Fig. 8. 1975 plot showing a blanket of dead grass cover mostly of annual rye on 15 May 1976. Fig. 9. 1975 plot showing an excellent vegetation cover of red fescue on 25 May 1978, native species like horsetails and mosses formed an important component of the vegetation. Fig. 10. 1975 plot on 6 September 1978 with an excellent vegetation cover of red fescue, birdsfoot trefoil and mosses. Fig. 11. 1977 plot on 6 September 1978 with excellent cover of red fescue and birdsfoot trefoil.

a seeded mined area to return to stable productive farm land, b) 10 years for it to return to stable productive pasture land, and c) 25 years for the mined area to be a productive wildlife habitat. The sequences in the Stabilization Process at Buchans may be similar to the above. However the time scales will alter because of differences in climate, soil and mining methods.

3.2 Chemical Composition of Tailing and Slimes

The results of chemical analysis of the bulk samples of slimes and tailings are presented in Table 2. The tailings contained higher proportions of sand and lower proportions of silt than the slimes. Both the tailings and the slimes were poor in nitrogen and organic matter. Except for phosphorus and magnesium, available and total concentrations of all cations were lower in slimes than in the tailings. The same was true for heavy metals (Table 2). The low pH, lack of organic matter and poor nutrient levels in the tailings and slimes presented poor conditions for the normal growth of the seeded species. These were easily corrected by the application of fertilizers, lime and seeding of annual rye. The annual rye produced a mantle of organic material in the form of dead first year growth and helped improve the soil conditions (Fig. 10).

The normal, toxic and "maximum allowable" levels of cadmium, copper, lead, molybdenum, nickel and zinc are summarized in Appendices I, II and III respectively. These metals (except lead) are essential in

Table 2. Physical and chemical analysis of sand slimes and mine tailings from Buchans, Newfoundland.

Element	Units	SAMPLE			
		Sand slimes		Tailings	
		0-15 cm	15.1-25 cm	0-15 cm	15.1-22 cm
Sand	% dry wt.	35.0	68.0	84.0	79.0
Silt	% dry wt.	64.9	32.0	16.0	21.0
Clay	% dry wt.	0.1	0.0	0.0	0.0
pH		5.60	5.40	6.45	6.65
Organic matter	% dry wt.	0.24	0.07	0.28	0.69
Nitrogen (total)	ppm dry wt.	15	20	15	20
" (available)	"	5.6	5.6	6.0	5.6
Phosphorus (total)	ppm dry wt.	171.3	233.8	328.8	246.3
" (available)	"	1.39	1.20	0.21	0.29
Potassium (total)	ppm dry wt.	1670.8	140.4	5254.6	5157.8
" (available)	"	20.3	14.6	40.2	42.5
Calcium (total)	ppm dry wt.	6320.1	5981.1	9879.7	11308.4
" (available)	"	216.3	216.3	1673.3	1870.6
Magnesium (total)	ppm dry wt.	1222.0	1190.3	8499.5	8911.1
" (available)	"	18.8	11.9	9.2	16.5
Manganese (total)	ppm dry wt.	169.3	211.6	301.5	370.3
" (available)	"	8.0	2.5	18.0	22.6
Sodium (total)	ppm dry wt.	653.8	605.4	435.9	339.0
" (available)	"	5.9	5.1	6.1	12.8
Cobalt (total)	ppm dry wt.	5.5	4.5	9.0	12.0
" (available)	"	-	-	-	-
Copper (total)	ppm dry wt.	15.0	14.5	823.3	920.2
" (available)	"	0.56	0.20	8.1	3.6
Zinc (total)	ppm dry wt.	52.5	31.5	3874.4	5424.2
" (available)	"	0.56	0.80	151.8	85.4

Table 2 (Concl'd.)

Element	Units	SAMPLE			
		Sand slimes		Tailings	
		0-15 cm	15.1-25 cm	0-15 cm	15.1-22 cm
Lead (total)	ppm dry wt.	10.0	10.0	25.0	25.0
" (available)	"	-	-	-	-
Iron (total)	ppm dry wt.	9080.6	8717.4	20655.4	29106.4
" (available)	"	-	-	-	-
Nickel (total)	ppm dry wt.	42.5	39.5	43.5	41.5
" (available)	"	3.4	3.2	3.7	3.6
Aluminum (total)	ppm dry wt.	7829.2	8252.4	22482.5	22694.1
" (available)	"	-	-	-	-
Chromium (total)	ppm dry wt.	26.0	26.5	27.0	30.0
" (available)	"	0.48	0.52	0.60	0.48

traces for the normal growth of plants but become toxic if present above the threshold levels. Their availability is pH dependent. In general these are more readily available under acidic than under alkaline conditions.

A comparison of the available and total concentrations of heavy metals in tailings and slimes (Table 2) with those in the soils from elsewhere (Appendix I) and with data given by Isaac and Kerber (1971) show that: (i) The concentration of cobalt and manganese in slimes and tailings were below the reported levels in soils and do not pose any serious hazard to plant or animal life. (ii) The concentration of total copper was 40-times greater in tailings (up to 920 ppm) than reported in soils and was within the reported limits in the slimes (15 ppm). The level of available copper in tailings as well as slimes were within the reported limits in soils (Table 2 and Appendix I). These concentrations do not appear to have any adverse effects on the plant species established on the revegetated tailings and slimes. (iii) Total nickel concentrations were twice the reported concentrations in soils (Appendix I) and lower than reported in the sludge applied to Michigan soils (Appendix I). (iv) The available concentrations of nickel were comparable to the reported levels. The concentrations of lead in tailings and slimes were within the reported limits (Tables 3, Appendices I & II) and should not pose any serious hazard to plants. However, the response of receptor herbivores to repeated ingestion of these levels of lead and additional levels through dust on the vegetation should be studied further to assess the suitability of the use

of the revegetated mine tailings as cattle grounds. (v) Zinc concentrations in the tailings were also 8 - 14 times higher than reported from soils in other areas, but the concentrations of Zn in the slimes were 100 times lower than in the tailings and were within the reported levels in soils (Tables 2 and 3). Zinc concentrations > 300 ppm in soils could be toxic to plants (MacLean and Langille 1973).

Over 93% of Cu, Zn, Cd and Pb applied to soil has been reported to accumulate in soil. However less than 7% of the accumulated levels in soils were reported to be absorbed by vegetation on experimental plots treated with sewage effluent (Siddle, Hook and Kardos 1976). From the presently available information, zinc may be the only element in soil of concern to vegetation and eventually to animals in the ASARCO revegetated areas.

3.3 Chemical Composition of Foliage Samples

Foliage of a number of species growing on mine tailings, edge of pond with slime discharge and natural undisturbed forest were analysed for N, P, K, Ca, Mg, Mn, Na, Fe, Cu, Co, Ni, Al, B, Pb, Zn and Cr.

The levels of major nutrients (N, P, K, Ca, Mg, Na) presented in Table 3, were within the reported levels in healthy foliage (Singh and Bhure 1974; van Nostrand and Bhure 1973) of firs and spruces from plantations and natural forest stands in Newfoundland.

The comparison of the heavy metals in foliage of different plant species grown on tailings from Buchans showed that the concentrations were within the reported limits (Table 3, Appendices I & II). This is because of the low percent of the total being absorbed by the

Table 3. Total concentration of various elements in the samples of vegetation from mine tailings and undisturbed forest - Buchans, Newfoundland.

Habitat	Species	Element													
		Parts Per Million (Dry wt. basis)													
		% N	P	K	Ca	Mg	Mn	Na	Fe	Cu	Co	Ni	Al	Pb	Zn	Cr
Revegetated mine tailings	Alder	3.56	1232	13660	10340	1802	323	259	1	1	0.65	4.44	-	9.50	2	0.85
	Alder	4.00	2715	17834	11952	2134	938	671	920	29	1.65	5.30	400	18.40	80	1.00
	Willow	2.92	1787	15936	17454	1897	190	182	7	8	2.15	3.30	-	9.50	245	0.90
	Horsetail	2.45	8375	39841	26418	4031	136	201	1	1	2.60	5.40	-	6.50	1	1.95
	Grass mixture (seeded)	3.14	3525	37944	8774	1138	146	517	302	14	2.10	4.20	130	5.85	33	1.89
	Balsam fir (chlorotic with SO_2 symptoms)	1.31	550	4600	9770	616	170	776	4	2	0.70	2.50	-	7.00	24	0.60
John's Pond (slime)	Balsam fir:															
	Healthy* - 1974 growth	1.92	695	4458	12284	522	1092	326	11	7	1.0	2.15	60	7.00	191	0.75
	- 1975 growth	2.26	2135	12616	6213	711	502	182	2	8	0.75	3.20	-	6.50	87	1.10
	Dead - 1974 growth	1.05	1232	4648	8442	758	670	297	119	9	0.75	3.75	340	27.50	97	0.75
	White spruce:															
	Healthy* - 1973 growth	1.04	797	3035	10387	284	2059	182	8	6	1.30	2.25	-	9.50	194	1.35
	- 1974 growth	1.14	947	2845	9486	426	2078	287	86	8	2.25	6.75	80	15.25	151	2.13
	- 1975 growth	1.40	1512	7304	5075	521	1092	326	62	7	0.76	2.75	70	8.26	84	0.43
	Chlorotic - 1973 growth	1.02	947	3052	10103	379	2031	210	82	6	0.50	2.70	80	6.50	166	0.60
	(yellow) - 1974 growth	0.88	1320	4980	7968	1091	1082	220	71	8	0.40	4.10	60	5.00	101	0.30
	- 1975 growth	0.78	1285	6024	6877	948	996	229	72	5	0.60	4.65	70	7.00	73	0.35
John's Pond	Balsam fir) White spruce) mixed litter	0.85	125	1375	22339	664	1351	182	260	43	1.20	6.50	290	290.00	833	3.00

*Samples from healthy forest approximately 100 metres from the edge of the pond with sand slime discharge.

plants. The vegetation itself may not pose any serious hazard to the grazing animals; however, dust rich in heavy metals accumulated on vegetation and as a result ingested with the feed may pose hazard conditions for herbivores. Field tests on animals must be run before making a final judgement on the suitability of grasses and other herbs (grown on tailings) as feed.

ACKNOWLEDGEMENTS

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Appendices I - III

Appendix I. Typical concentrations of cadmium, copper, lead, molybdenum, nickel and zinc in soils, plants and animals.

Appendix II. Toxic levels of cadmium, copper, lead, molybdenum, nickel and zinc in soils, plants and animals.

Appendix III. Maximum total concentrations of cadmium, copper, lead, molybdenum, nickel and zinc allowed after addition/accumulations.

Appendix I. Typical concentrations of cadmium, copper, lead, molybdenum, nickel and zinc in soils, plants and animals.

Heavy metal	Typical concentrations (ppm/dry wt)		
	Soils	Plants	Animals
Cadmium (cd)	A. McLean (personal communications) 0.4 - minimum recommended in soils	Allaway 1968: 0.2 to 0.8 Thomas et al. 1972: 0.02 - cabbage 0.03 - pears 0.02 - tomatoes 0.02 - potatoes	-
Copper (Cu)	MacLean and Langille 1973: 20 - lead rich soil 19 - intensively farmed 18 - lightly farmed areas 22 - roadside Lunt 1959: 61 - manure	Allaway 1968: 4-15 in general MacLean & Langille 1973: 12.3 - lead rich area 12.9 - intensively farmed 8.3 - lightly farmed areas 11.7 - roadside 11.1 - above ground parts 9.4 - underground parts Nilsson 1972: 1.6 - 3.5 in 1 year old spruce needle 1.4 - 2.7 in 4 year old spruce needles Warren 1972: Lettuce 60 ppm (Ash) Cabbage 40 ppm " Potato 100 ppm " Carrot 70 ppm " Beet 80 ppm "	-

Appendix 1. (Cont'd.)

Heavy metal	Typical concentrations (ppm/dry wt)		
	Soils	Plants	Animals
Lead (Pb)	Warren & Delavault 1961: 0.1 - 1.0 MacLean et al. 1969: 6-14 Ontario: 11 Chisholm & Bishop 1967: 50 Mitchell & Reith 1966: 30-40 (late winter) MacLean & Langille 1973: 55 - lead rich soil 31 - intensive farming 36 - roadside 26 - lightly farmed California Air Resource Based 1973: > 50 except in remote areas of California Wu and Antonovics 1976: 0.4 ± 0.2 365 ± 17 extractable (roadside)	MacLean & Langille 1973: 5.6 - lead rich soil 6.2 - intensively farmed 6.2 - roadside vegetation 2.0 - lightly farmed 6.8 - above ground parts 4.7 - below ground parts Thomas et al. 1972: 0.03 - peas 0.08 - cabbage 0.06 - tomatoes 0.04 - potatoes 0.05 - whole apples 0.03 - whole pears Allaway 1968: 0.1 - 10 Warren 1972: Lettuce 20 ppm (Ash) Cabbage 16 ppm " Potato 40 ppm " Carrot 20 ppm " Nilsson 1972: 0.8 - 3.0 1 yr old spruce foliage 2.8 - 4.7 4 yr old spruce Quarles III et al., 1974: 6.6 - in plants near highway 6.1 - epiplytic moss Marten and Hammond 1966: 0.1 - 1.0 ppm Wu and Antonovics 1976: 4 ± 0.5 (control) 313 ± 28 (roadside)	Donovan et al. 1969: Cow: - a) Blood 0.08 - 0.24 (Fresh wt. basis) b) Milk 0.06 - 0.08 (Fresh wt. basis) c) Faeces - 15.0 - 33.0 Horses - 0.09 - 0.11 Faeces - 11.7 Williamson & Evans 1972: 700 (fresh wt. basis) - insects near a highway Meltzer 1972: 270 ppm (fresh wt. - earthworms) 13.2 - Blarina, highway samples 4.2 - Blarina control samples 41.9 - Blarina from highway samples 7.2 - Blarina control samples Warren 1972: Normal ingestions by humans, 0.3 - 0.4 mg/day from air, water and food

Appendix I. (Cont'd.)

Heavy metal	Typical concentrations (ppm/dry wt)		
	Soils	Plants	Animals
	Quarles III, et al. 1974: 17.7 ± 3.7 California Air Resource Board 1967: 16	Warren 1972: 40 ppm (ash basis) in Douglas fir	
Molybdenum (Mo)	MacLean and Langille 1973: 2.8 1.7 2.3 0.9	MacLean and Langille 1973: 0.11 0.13 0.22 0.12 Warren 1972: 50 - 100 (Fireweed, ash basis) 17000 (fireweed growing on Mo - Ore., ash basis) Lettuce 5 ppm (Ash) Cabbage 30 ppm " Potato 16 ppm " Carrot 30 ppm "	
Nickel	Carlson & Menzies 1971: Trace to 150 - Sewage sludge from Michigan 0 - 0.75 — sewage sludge from Santiago Hinsley et al. 1972: 23 (total) - corn field 2.3 - 9.9 (extractable) - corn field 8 - Ont. soils Nilsson 1972: 18 - 20 (total)	Hinsley et al. 1972: 2.8 - corn tissue 2.3 - corn grain Nilsson 1972: 1.2 - 2.0 (1 yr old spruce needles) 1.0 - 2.6 (7 yr old needles 2.7 - 5.6 (litter)	

Appendix I.(Cont'd.)

Heavy metal	Typical concentrations (ppm/dry wt)		
	Soils	Plants	Animals
Zinc (Zn)	MacLean & Langille 1973: 355 418 426 451 McLean, A. (1976, personal communication) - 250 ppm (max. recommended) Lunt (1959): 150 in manure	Allaway 1968 8-15 MacLean and Langille 1973: 53.8 44.8 34.7 46.2 Nilsson 1972: 27 - 89 — 1 yr old spruce needles 39 - 106 — 4 yr old spruce needles Warren 1972: Lettuce 400 ppm (Ash) Cabbage 300 ppm " Potato 320 ppm " Carrot 420 ppm "	

Appendix II. Toxic levels of cadmium, copper, lead, molybdenum, nickel, and zinc in soils, plants and animals.

Heavy metal	Toxic Levels (ppm/dry wt)		
	Soils	Plants	Animals
Cadmium (Cd)		Leeper 1972: 30 in plants in general	
Copper (Cu)			Underwood 1971: Copper poisoning in sheep grazing on grasses with 50-60 ppm of Cu 400 ppm accumulation in cattle Agr. Canada (Personal communication): 125-325 toxic to livestock
Lead (Pb)	Lag et al. 1970: Vegetation sparse on soils with 47,000 ppm Depression in photosynthesis in spruce growing on soil with 32,000 ppm of soluble lead		Donovan et al. 1969: Horses died where lead was > 800 ppm (fresh wt. basis) in vegetation. 25 ppm - kidney (fresh wt. basis) 10 ppm - liver Agriculture Canada: 3-20 ppm in feed is toxic to animals. U.S. Publ. Health Service 1965: 474 mg/kg/day of PbCl in diet leads to classical lead poisoning in 8 months.

Appendix II.(Cont'd.)

Heavy metal	Toxic Levels (ppm/dry wt) Soils	Plants	Animals
Lead (Pb)			Kao and Forbes 1973: 300 ppm in diet — rats fed had lower body wt. Goyer, Moore and Krigman 1970: Anaemia in rats fed with water at levels 420 mg/g/day Hammond & Aronson 1964: 6,000-7,000 mg/kg/day in diet is fatal to cattle 150 ppm lead in total ration dry matter toxic to livestock. Agriculture Canada (personal communication): 3-20 ppm in dry feed toxic to livestock
Molybdenum (Mo)			Agriculture Canada (Personal communication): 100 - 1000 in feed toxic to livestock
Zinc (Zn)	> 300 in soil toxic to plants	Leeper 1972: 500	Agriculture Canada (Personal communication): 1,500 - 3,000 in feed toxic to livestock

Appendix III. Maximum total concentrations of cadmium, copper, lead, molybdenum, nickel and zinc allowed after addition/accumulation.

Heavy metal	Maximum total conc. allowed after addition/accumulation (ppm/dry wt)		
	Soils	Plants	Animals
Cadmium (Cd)	McLean, A. (Personal Communication) 0.4 McBride et al., 1977. 17 kg/ha		
Copper (Cu)	Ontario: 50 McBride et al., 1979: 435 kg/ha		
Lead (Pb)	Ontario: 40 California Air Resource Board: 17	Donovan et al. 1969: 5 ppm in plants used as food Thomas et al. 1972: 5-7 in plants consumed as food 3 - apples & pears 10 - dry herbs 2 - other vegetables 7 - in apples (in Canada)	Donovan et al. 1969: ≤ 0.1 ppm in drinking water Maines et al 1975: U.S. Drinking water Standard - ≤ 0.05 ppm in potable water
Nickel (Ni)	Ontario: 16		
Zinc (Zn)	Ontario: 160 MacLean 1974: 250 ppm in soil restricted growth of corn, 50 in acid soils restricted growth of lettuce. McBride et al. 1977: 870 kg/ha		
Manganese	Frischknecht 1978: > 5 ppm toxic to plants. Crops remove only 7 oz/acre		